

JPL

Working to Fix the Huygens Relay Link

Les Deutsch

Jet Propulsion Laboratory

February 15, 2001



Working to Fix the Huygens Relay Link

Acknowledgements

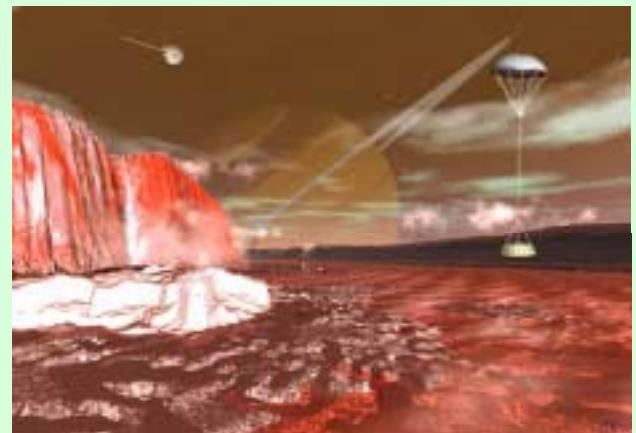
- Many JPLers are involved in working on this problems and others, like Richard Horttor, were instrumental in discovering sand defining the anomaly
- The JPL support team for the HRTF includes
 - Ken Andrews
 - Gil Chinn
 - Dariush Divsalar
 - Sam Dolinar
 - Jon Hamkins
 - Bill Hurd
 - Jerry Jones
 - Norm Lay
 - Earl Maize
 - Fabrizio Pollara
- ESA has put some of its best people on this task as well, and it is a pleasure to work with them
- Although I get the honor of giving the talks, these people are the force behind the results



Working to Fix the Huygens Relay Link

Background

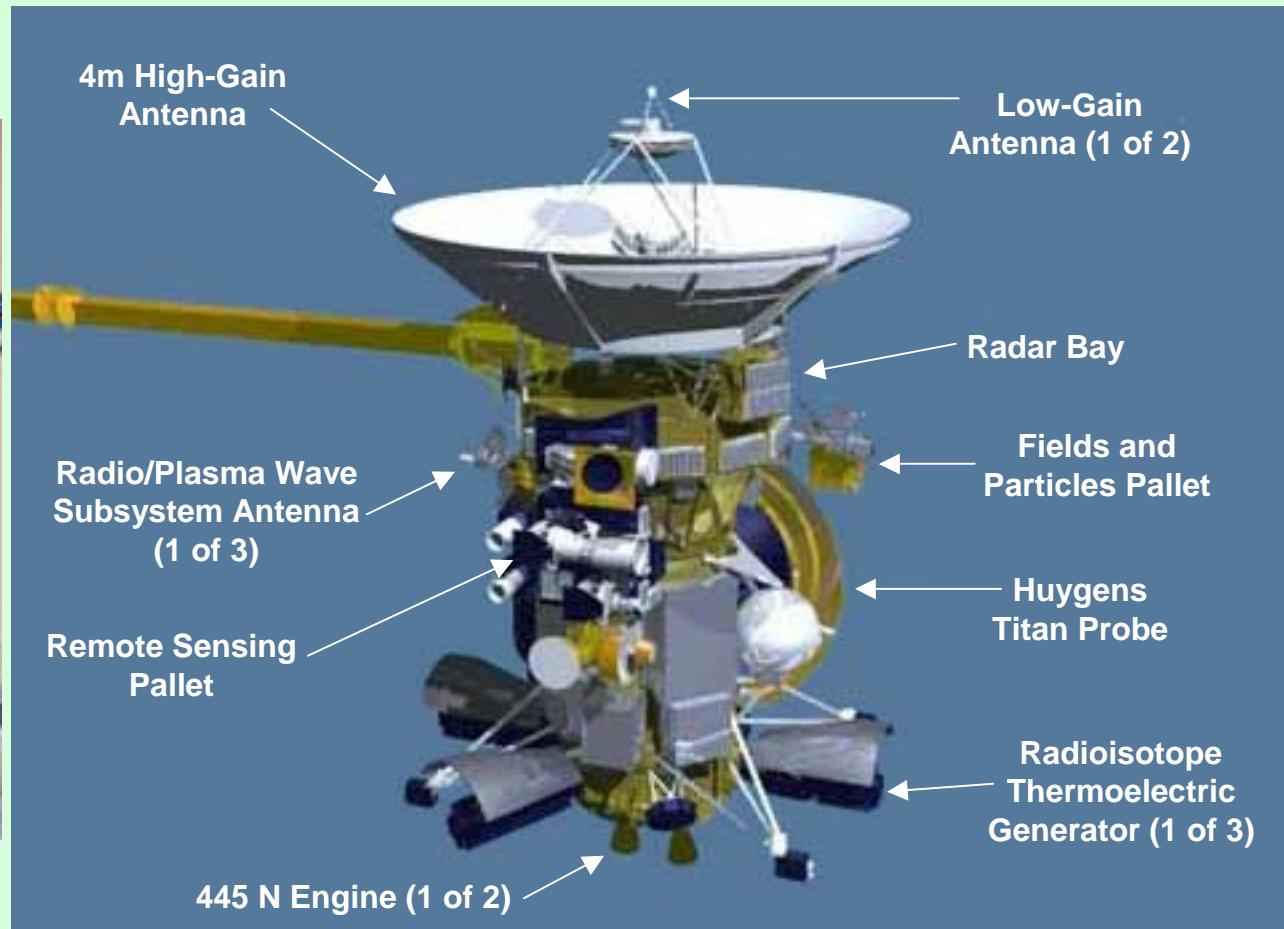
- The Huygens probe is carried by Cassini and is planned to be released just before Saturn arrival
- Huygens will fall into Titan's atmosphere as Cassini flies by
- Images, physical measurements, and radio science will be gathered during the descent into the atmosphere, expected to take about 150 minutes
- If Huygens survives on the surface, science will be performed until Cassini reaches Titan
- Cassini/Huygens is a joint ESA/NASA mission
- ESA built the Huygens spacecraft and both ends of the relay radio for the one-way telemetry link
- This link was tested on the ground before launch – but not under the kinds of signal dynamics expected in the real mission
- It was discovered in a DSN/Cassini test in February, 2000 that the link fails under Doppler rates typical of the expected mission!





Working to Fix the Huygens Relay Link

Cassini Spacecraft





Working to Fix the Huygens Relay Link

Huygens Scientific Experiments



GCMS – Gas Chromatograph and Mass Spectrometer

A very versatile gas chemical analyzer able to identify and quantify various Titan atmospheric constituents. If the Probe makes a safe landing it will measure surface composition.

ACP – Aerosol Collector and Pyrolyzer

Collects aerosols during descent phase at various atmospheric layers and then heats up the collected samples to produce pyrolysis products that will be flushed to the GCMS.

DISR - Descent Imager and Spectral Radiometer

Takes images and spectral measurements using several sensors from the ultraviolet to the infrared. Will observe clouds and Titan surface. Will also create mosaic panoramas.

HASI – Huygens Atmosphere Structure Instrument

Consists of a various set of sensors to measure the physical properties of the atmosphere such as temperature, pressure, electrical conductivity and permittivity.

DWE – Doppler Wind Experiment

Backed by the presence of Ultra stable Oscillators on the Probe and the Probe Avionics on the Orbiter, it will permit measurement of winds in Titan's atmosphere and may also help reconstitute the Probe flight dynamics during descent.

SSP – Surface Science Package

Contains several sensors capable of measuring physical properties of the surface like thermal, acoustic, dielectric and optical. It will also indicate impact deceleration and Probe attitude if stable enough on solid surface bed.

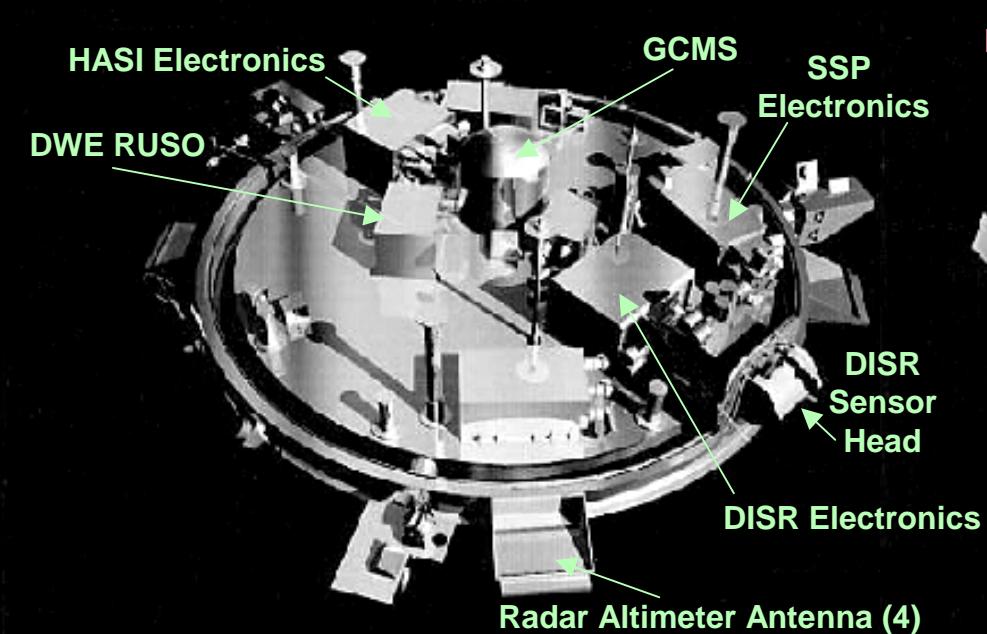


Working to Fix the Huygens Relay Link

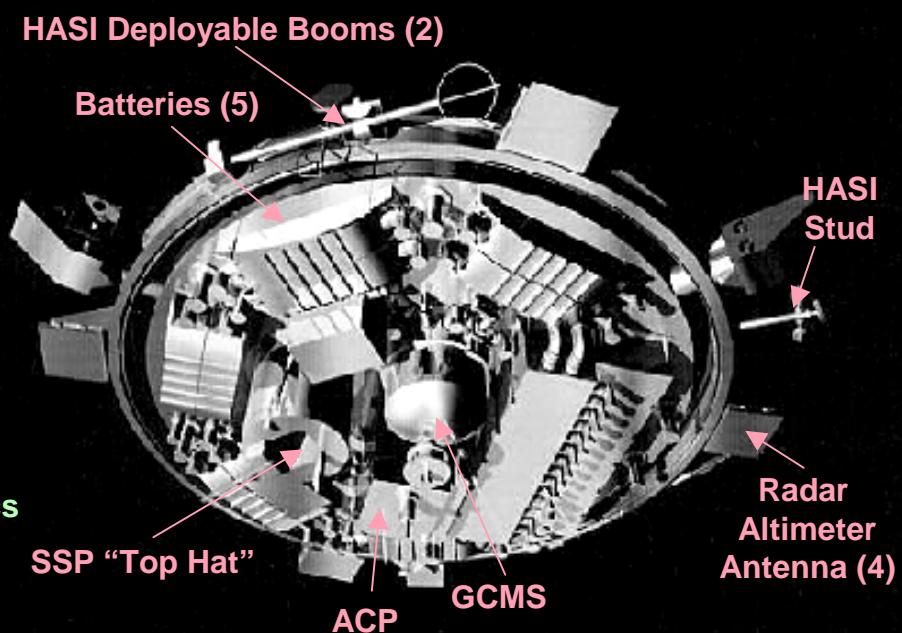
Huygens Titan Probe



Upper Side



Bottom Side



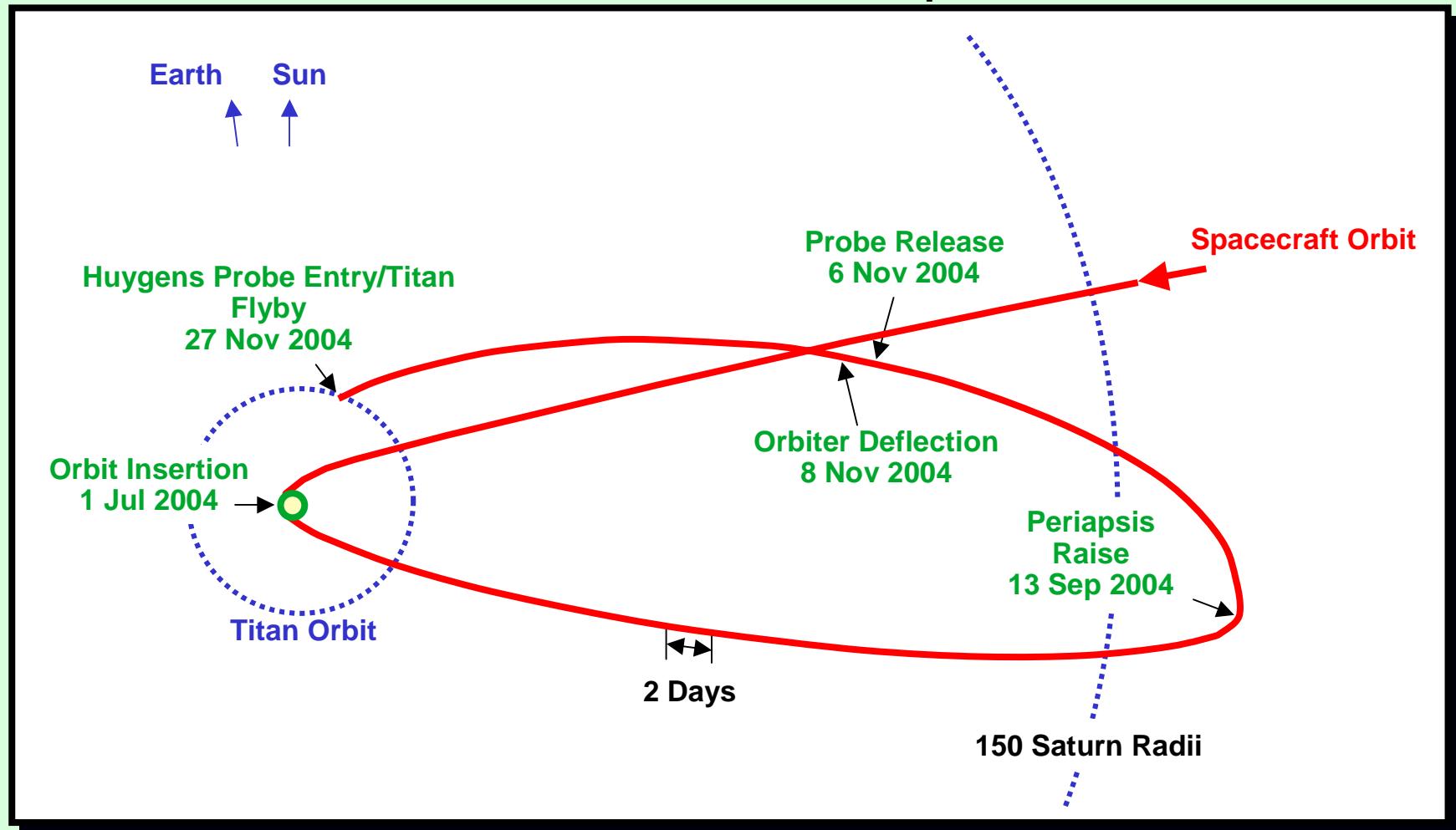


Working to Fix the Huygens Relay Link

Saturn Arrival and Initial Orbit



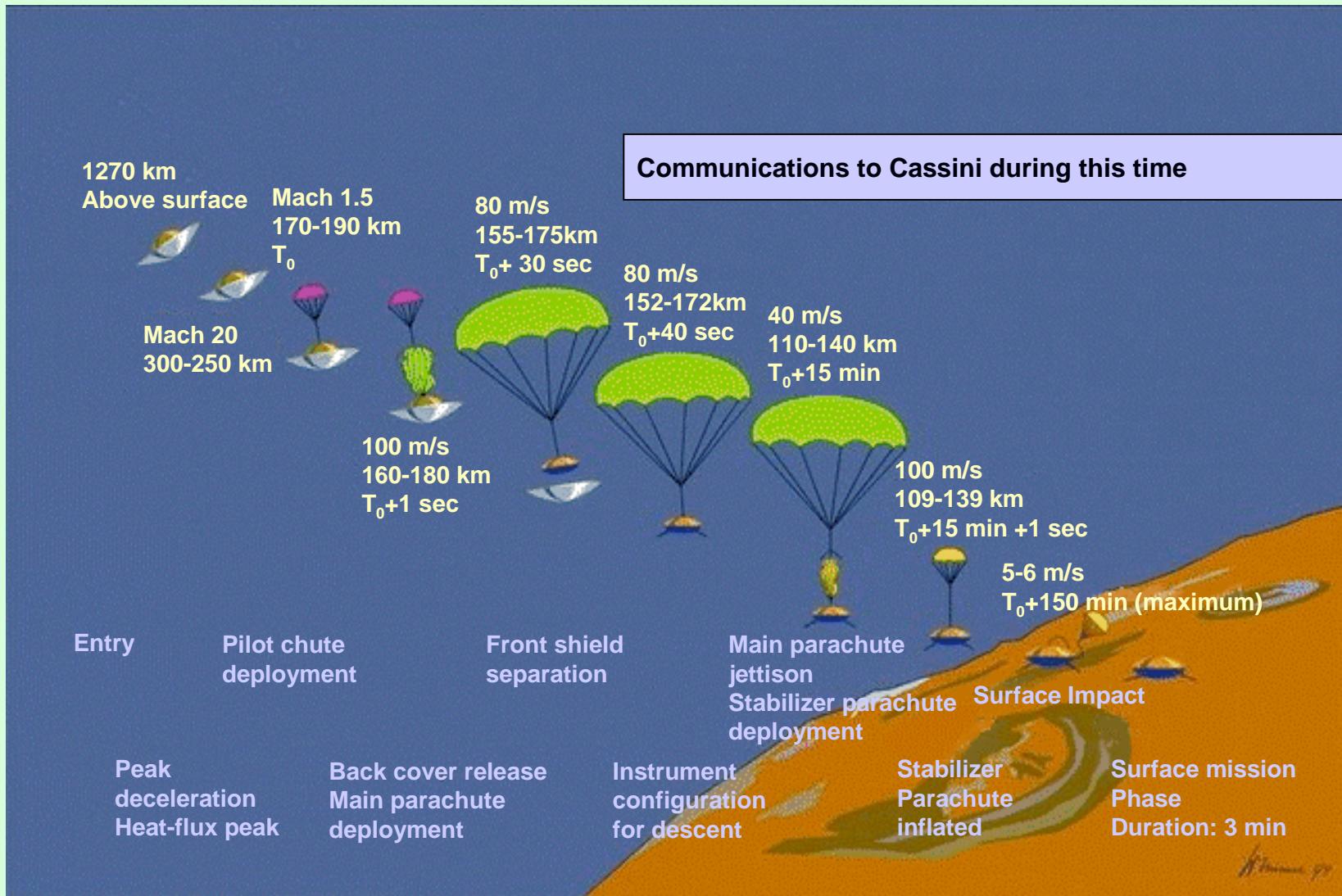
View from Saturn north pole





Working to Fix the Huygens Relay Link

Huygens Descent Sequence



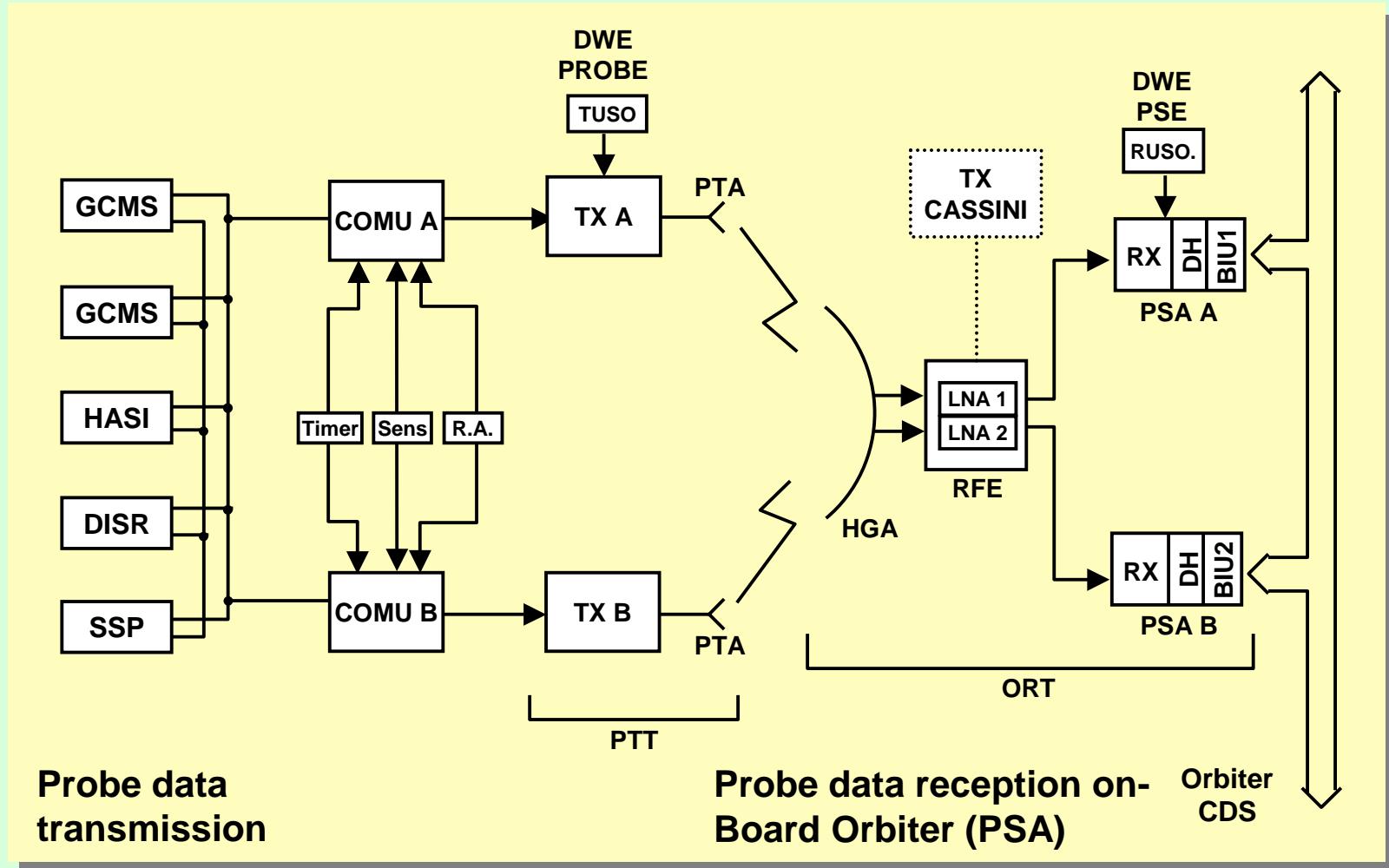
Working to Fix the Huygens Relay Link Probe Communications System



- Probe instruments generate fixed length packets that are stored in two buffers
- Probe software gathers these packets into frames
 - Seven packets in each 8192-bit frame
 - Reed-Solomon encoding
 - Frame sync word and header added
 - Differential encoding
 - Convolutional encoding with alternate symbol inversion
- Frames are transmitted to Cassini on two S-band channels
 - Different carrier frequencies
 - One channel delayed by 6 seconds
 - Data rate fixed at 16Kbps, so 1 frame/second in each channel



Working to Fix the Huygens Relay Link Communications Block Diagram



Probe data transmission

Probe data reception on-
Board Orbiter (PSA)

Orbiter
CDS



Working to Fix the Huygens Relay Link

Cassini's Probe Support Assembly (PSA)

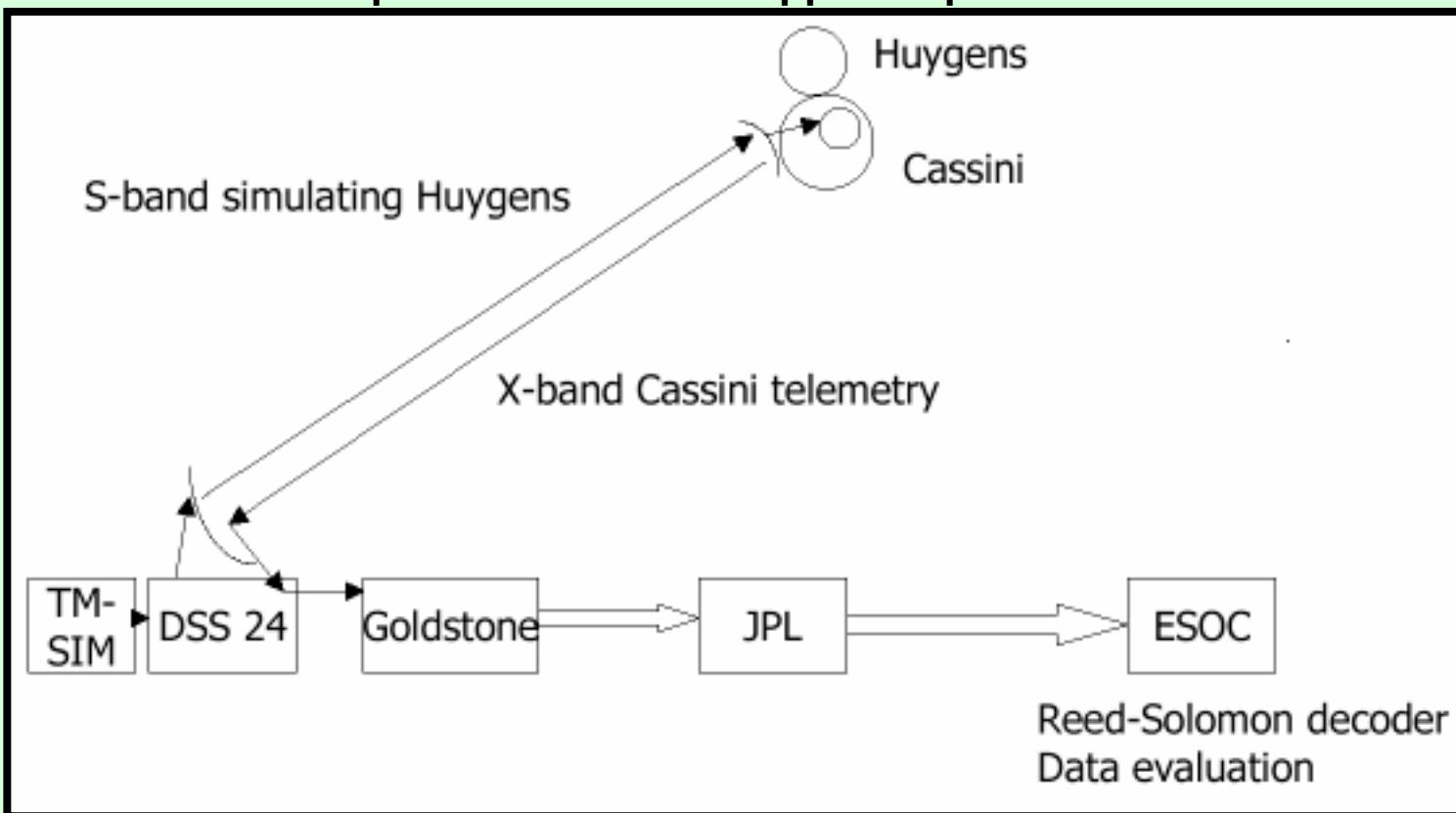
- The PSA on board Cassini receives the Huygens signals
- Carrier demodulation
- Subcarrier demodulation
- Bit detection (using classical DTTL)
- Viterbi decoding
- Frame sync
 - If in sync, frame is passed to Cassini CDH for further processing
 - If not, a dump packet is passed instead – no telemetry information
- Frame sync word stripped
- Remainder of frame is stuffed into a Cassini downlink frame and sent to Earth
- Housekeeping frames (with PSA status) are also sent to Earth



Working to Fix the Huygens Relay Link

PRT 1: First DSN Ground Testing

- A Probe Relay Test (PRT) was performed in February, 2000 to determine the performance of the hardware and software aboard Cassini for supporting the probe, telemetry to the ground, DSN-ESA communications, and ESA decoders
- Test simulated expected maximum Doppler of probe mission





Working to Fix the Huygens Relay Link

Test Results

- Expected all frames over a certain SNR to decode correctly at ESOC
- In fact, the majority of frames did not even synchronize in the PSA
- Many frames that were sent to the ground failed to RS-decode at ESOC despite the fact they should have had plenty of SNR
- Analysis of test results (conducted by Boris Smeds of ESOC) indicated:
 - The PSA tracked the carrier and subcarrier as expected
 - The bit sync DTTL failed to track the data
- It was later confirmed by Alenia (the Manufacturer of the PSA) that incorrect values for DTTL loop bandwidth had been used in the design
- There is insufficient bandwidth in the DTTL to track in the higher-Doppler periods of the mission



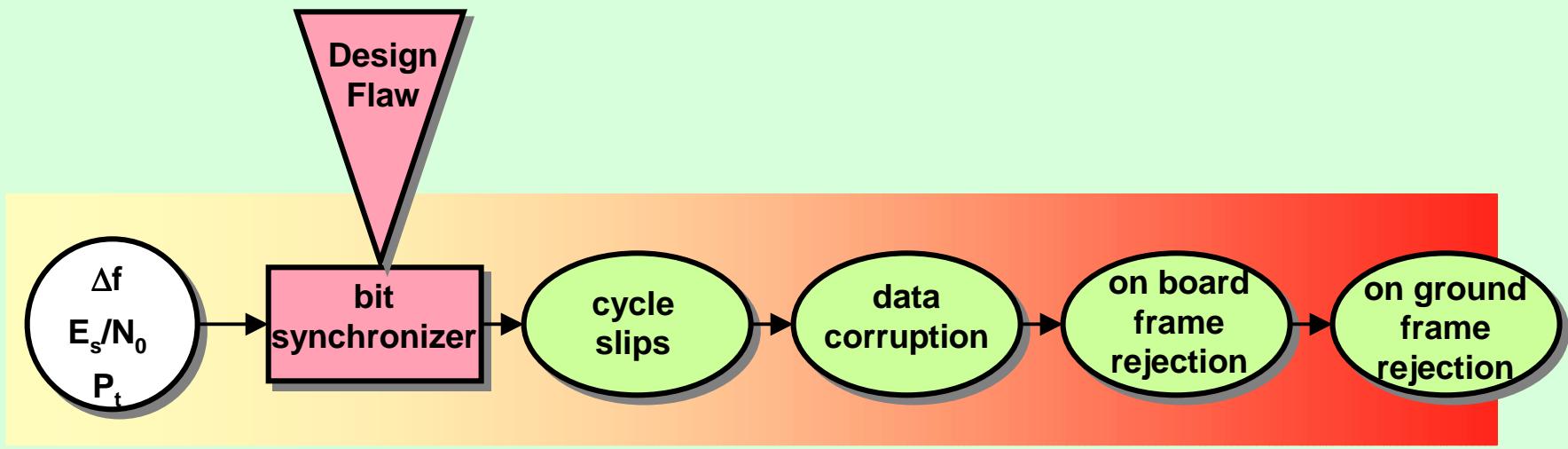
Working to Fix the Huygens Relay Link

The Huygens Recovery Task Force (HRTF)

- Coincident with a formal NASA/ESA board of inquiry, teams of people at NASA, JPL, and Alcatel (one of ESA's contractors) began investigating the problem and possible solutions
- In December, A formal letter was sent from ESA to NASA chartering the HRTF
- The HRTF is chaired by Kai Klaassen of ESTEC and co-chaired by Les Deutsch of JPL
- Membership includes ESTEC, ESOC, JPL, Alcatel, Alenia, GMV, and members of the Huygens instrument teams



Working to Fix the Huygens Relay Link Failure Mechanism



Relevant
Parameters

The
Problem

The
Effect





Working to Fix the Huygens Relay Link

HRTF Task Phasing



1 Jan 01

Failure Investigation

Testing FM/EM
Analyses
Modeling, verification

Recovery Design

Sensitivity analysis
Parameter verification
 Δf : flyby altitude/velocity
oscillator manipulation
 E_s/N_0 : ODT/antenna pointing
 P_t : data manipulation
zero packets
Corrupted data recovery

Options

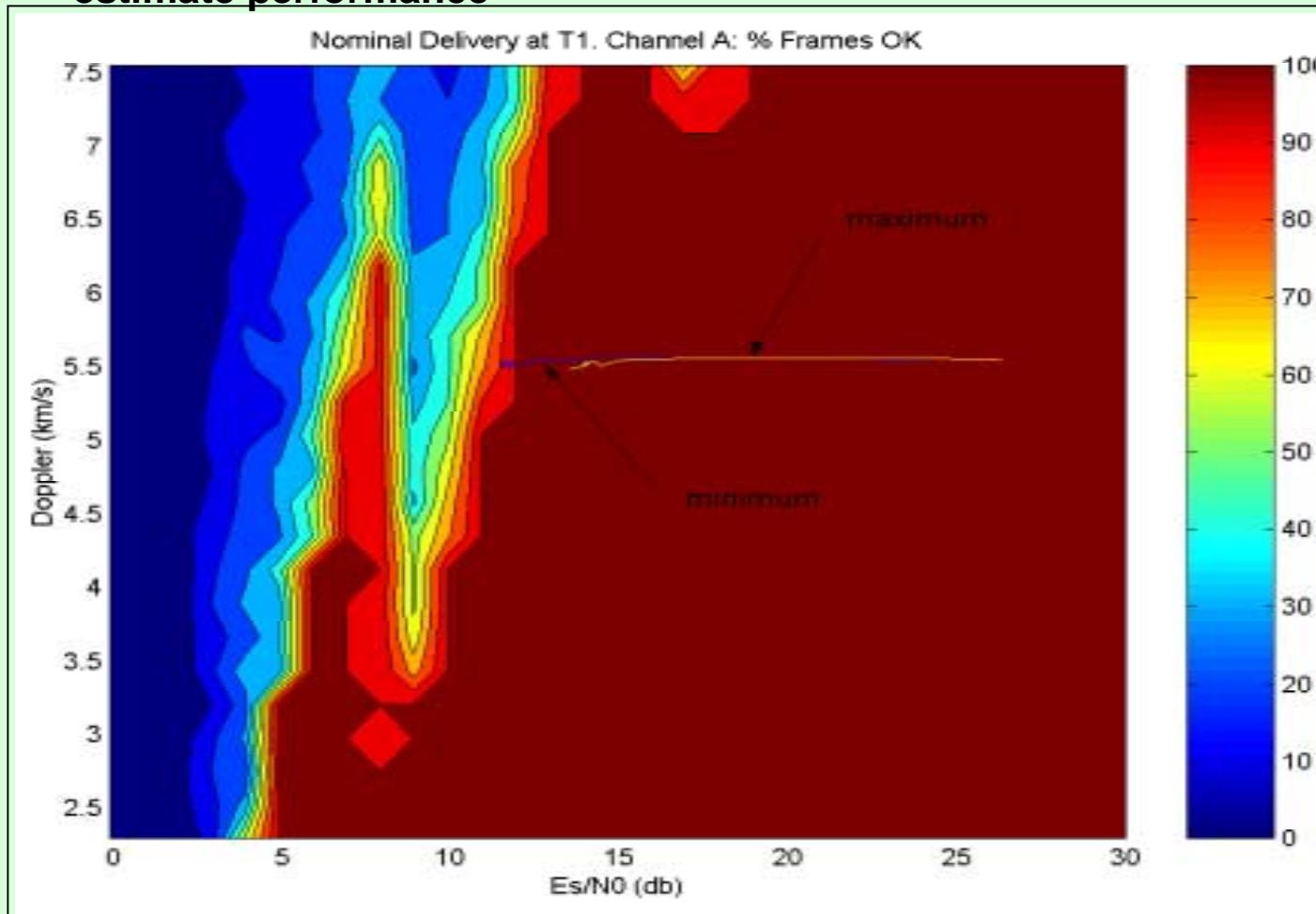
Gain/impact assessment
Design of options

30 Jun 01

Decision
ESA/NASA
Directors

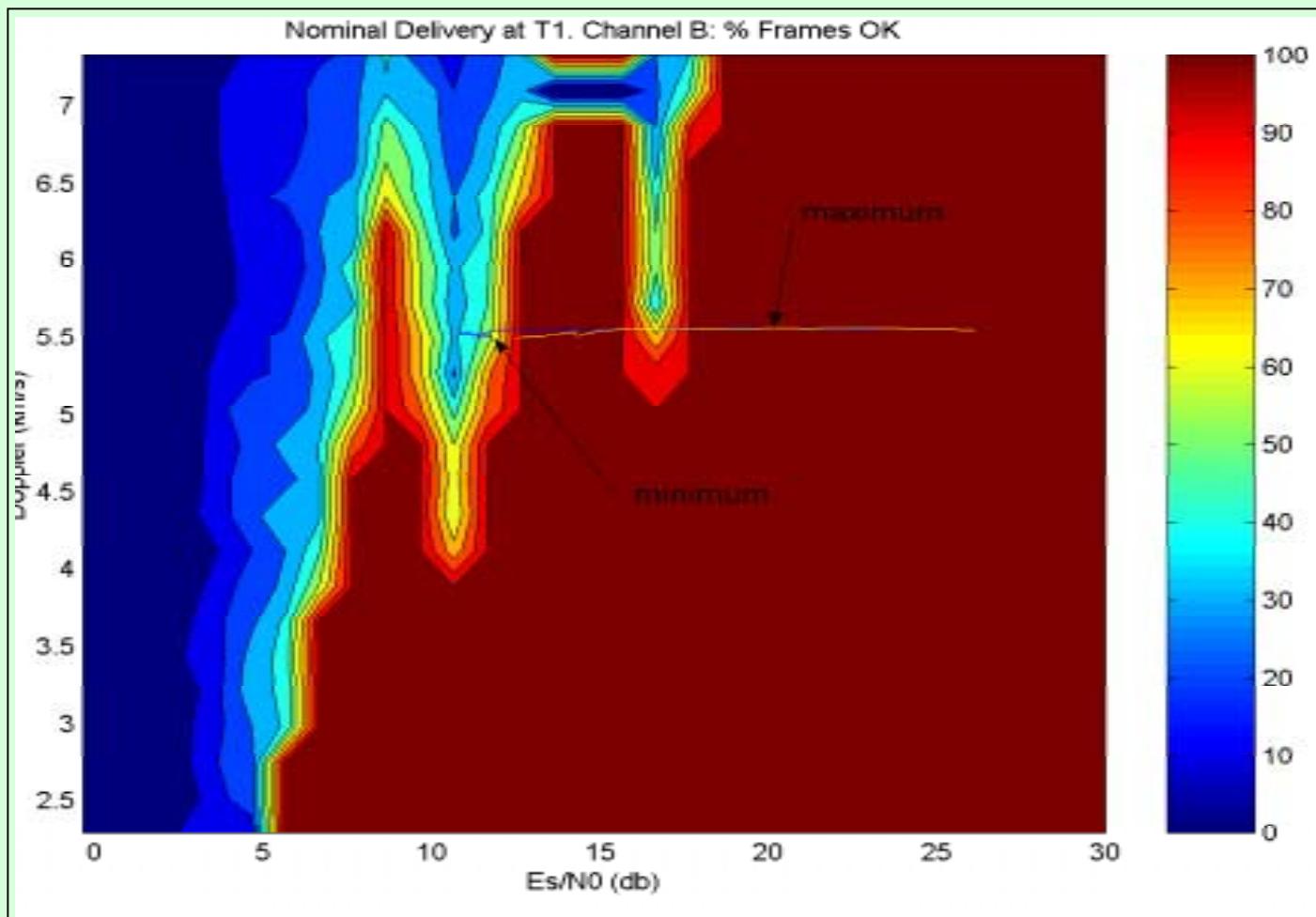
Working to Fix the Huygens Relay Link Bit Slip Function as a Contour - Channel A

- GMV has interpolated Boris' tables to get contour plots
- Various probe trajectories can be integrated against these contours to estimate performance



Working to Fix the Huygens Relay Link Bit Slip Function as a Contour - Channel B

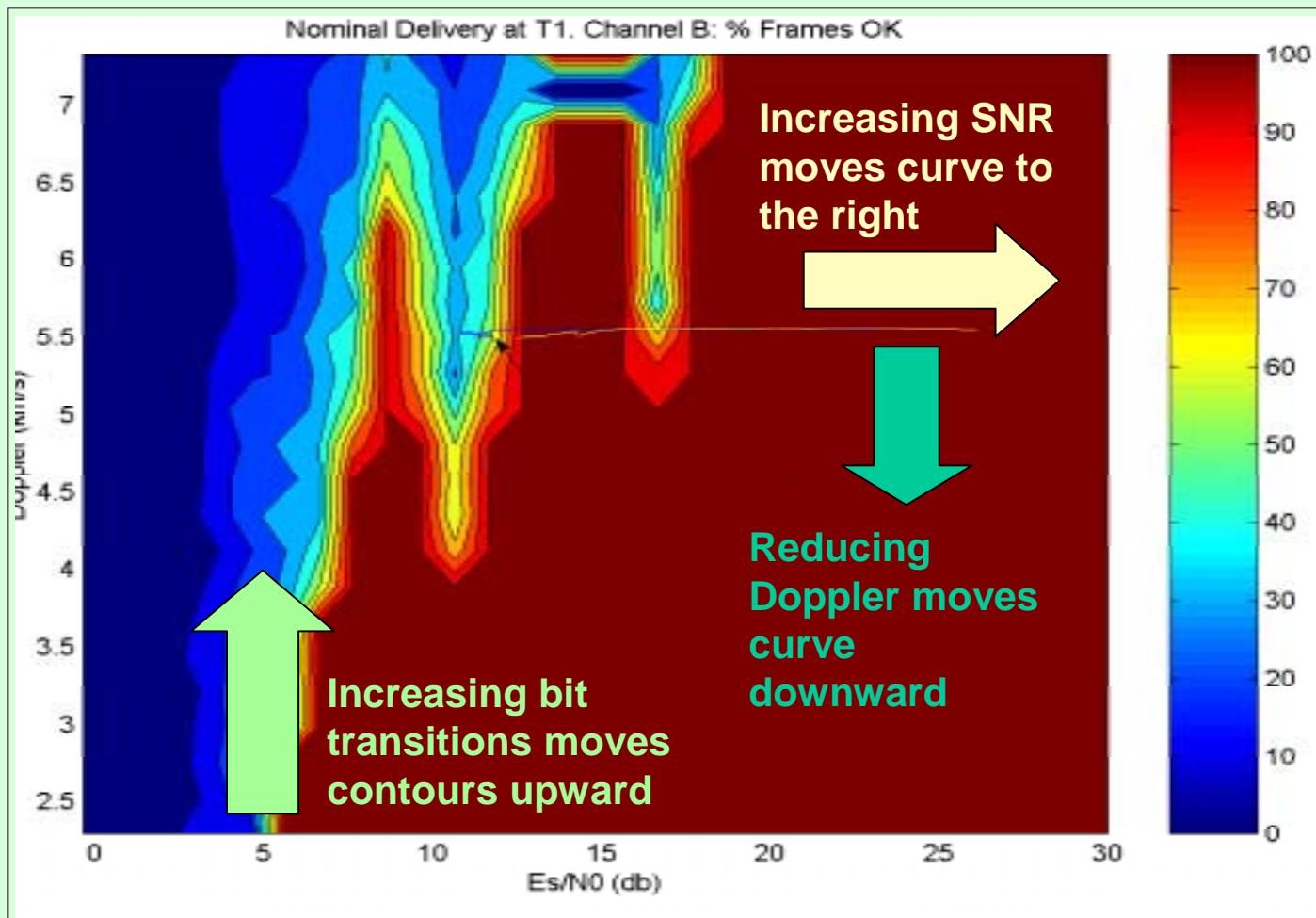
- Similar information for Channel B



Working to Fix the Huygens Relay Link

Ways to Improve Data Return

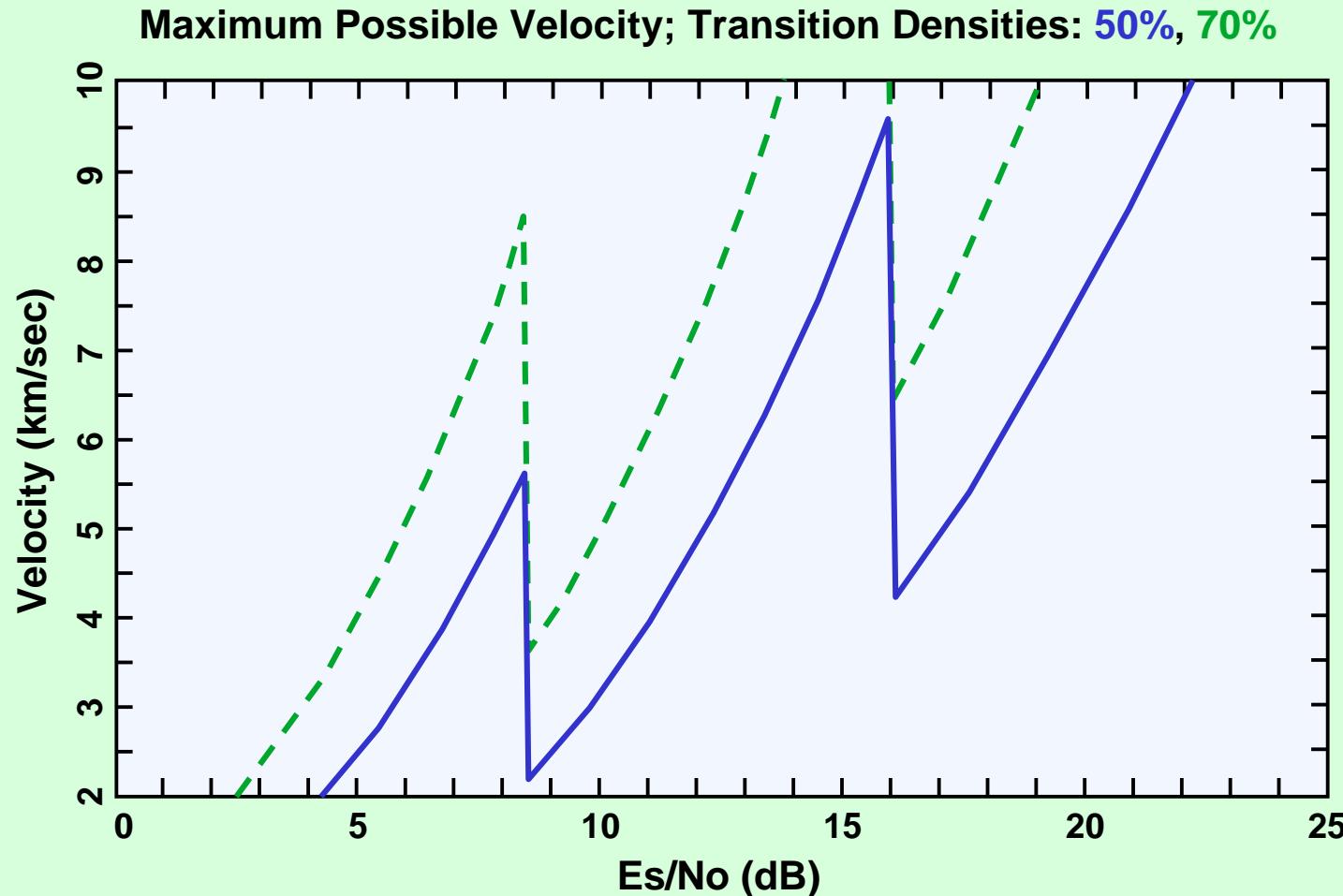
- Varying the critical parameters “moves” the probe curve with respect to the contours - resulting in more good data returned to Earth





Working to Fix the Huygens Relay Link

Model of Cycle Slip Regions





Working to Fix the Huygens Relay Link

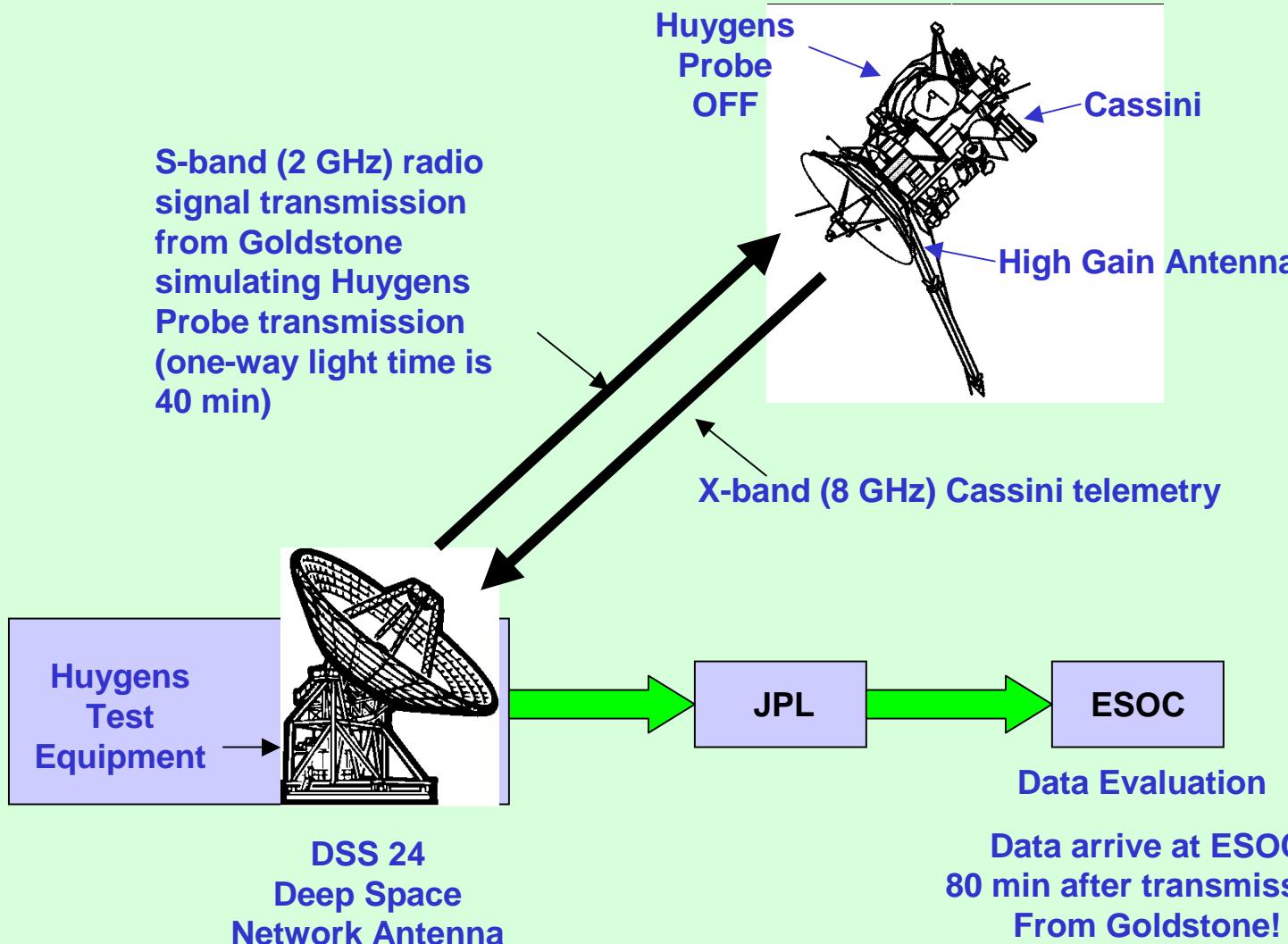
Modeled Results

- GMV modeling suggests that the percentage of frames received on the ground will be between 85% and 99% depending on the channel and some other error budget assumptions
- This all assumes that
 - EM performance is the same as Cassini
 - We can recover all the frames that are received on the ground
- The most important tasks in the first phase of the HRTF are meant confirm these assumptions:
- A second, more comprehensive DSN test has been completed that will determine the PSA rate of bit slipping function and allow us to calibrate the EM for future testing
- Modeling of the effects of bit slips on the data stream will be performed (at JPL) to predict packet and frame decoding rates



Working to Fix the Huygens Relay Link

Huygens Receiver Test #2 – Jan 31-Feb 4, 2001





Working to Fix the Huygens Relay Link

Huygens Receiver Test #2 – Some Photos





Working to Fix the Huygens Relay Link

Huygens Housekeeping Packets

- Information on the status of the PSA is transmitted to Earth in housekeeping packets

Time	Carr Lock	SC Lock	FFT Res.	Bit Sync.	Viterbi Dec.	Sync. Mark	AGC	Rec Freq	RSW
	R50019.raw	R5001C.raw	R5001B.raw	R5004C.raw	R50018.raw	R5002C.raw	XA8001.syn	XA8000.syn	R5003A
2001.035.03.03.46.731	1	1	1	0	0	0	512	-893.3188	6
2001.035.03.03.46.856	1	1	1	0	0	0	507	-892.496	6
2001.035.03.03.46.981	1	1	1	0	0	0	517	-891.4796	6
2001.035.03.03.47.106	1	1	1	0	0	0	522	-890.1244	6
2001.035.03.03.47.231	1	1	1	0	0	0	522	-892.98	6
2001.035.03.03.47.356	1	1	1	0	0	0	525	-892.98	6
2001.035.03.03.47.481	1	1	1	0	0	0	523	-891.6248	6
2001.035.03.03.47.606	1	1	1	1	0	0	515	-895.642	6
2001.035.03.03.47.731	1	1	1	0	1	1	518	-899.1752	6
2001.035.03.03.47.856	1	1	1	1	1	1	515	-898.8364	6
2001.035.03.03.47.981	1	1	1	1	1	1	509	-905.1768	6
2001.035.03.03.48.106	1	1	1	1	1	1	510	-909.3392	6
2001.035.03.03.48.231	1	1	1	1	1	1	511	-905.1768	6
2001.035.03.03.48.356	1	1	1	1	1	1	505	-909.5328	6
2001.035.03.03.48.481	1	1	1	1	1	1	518	-911.5172	6
2001.035.03.03.48.606	1	1	1	1	1	1	505	-911.372	6
2001.035.03.03.48.731	1	1	1	1	1	1	516	-908.0324	6
2001.035.03.03.48.856	1	1	1	1	1	1	510	-909.3392	6
2001.035.03.03.48.981	1	1	1	0	1	1	515	-907.8388	6
2001.035.03.03.49.106	1	1	1	1	1	1	509	-900.1916	6
2001.035.03.03.49.231	1	1	1	1	1	1	510	-895.8356	6
2001.035.03.03.49.356	1	1	1	1	1	1	513	-897.336	6
2001.035.03.03.49.481	1	1	1	1	1	1	515	-897.1424	6
2001.035.03.03.49.606	1	1	1	0	1	1	508	-898.3524	6
2001.035.03.03.49.731	1	1	1	0	1	1	512	-897.1424	6
2001.035.03.03.49.856	1	1	1	1	1	1	521	-891.9636	6
2001.035.03.03.49.981	1	1	1	0	1	1	505	-895.3032	6
2001.035.03.03.50.106	1	1	1	0	1	1	519	-897.4812	6
2001.035.03.03.50.231	1	1	1	0	1	1	521	-893.1252	6
2001.035.03.03.50.356	1	1	1	1	1	1	508	-893.464	6



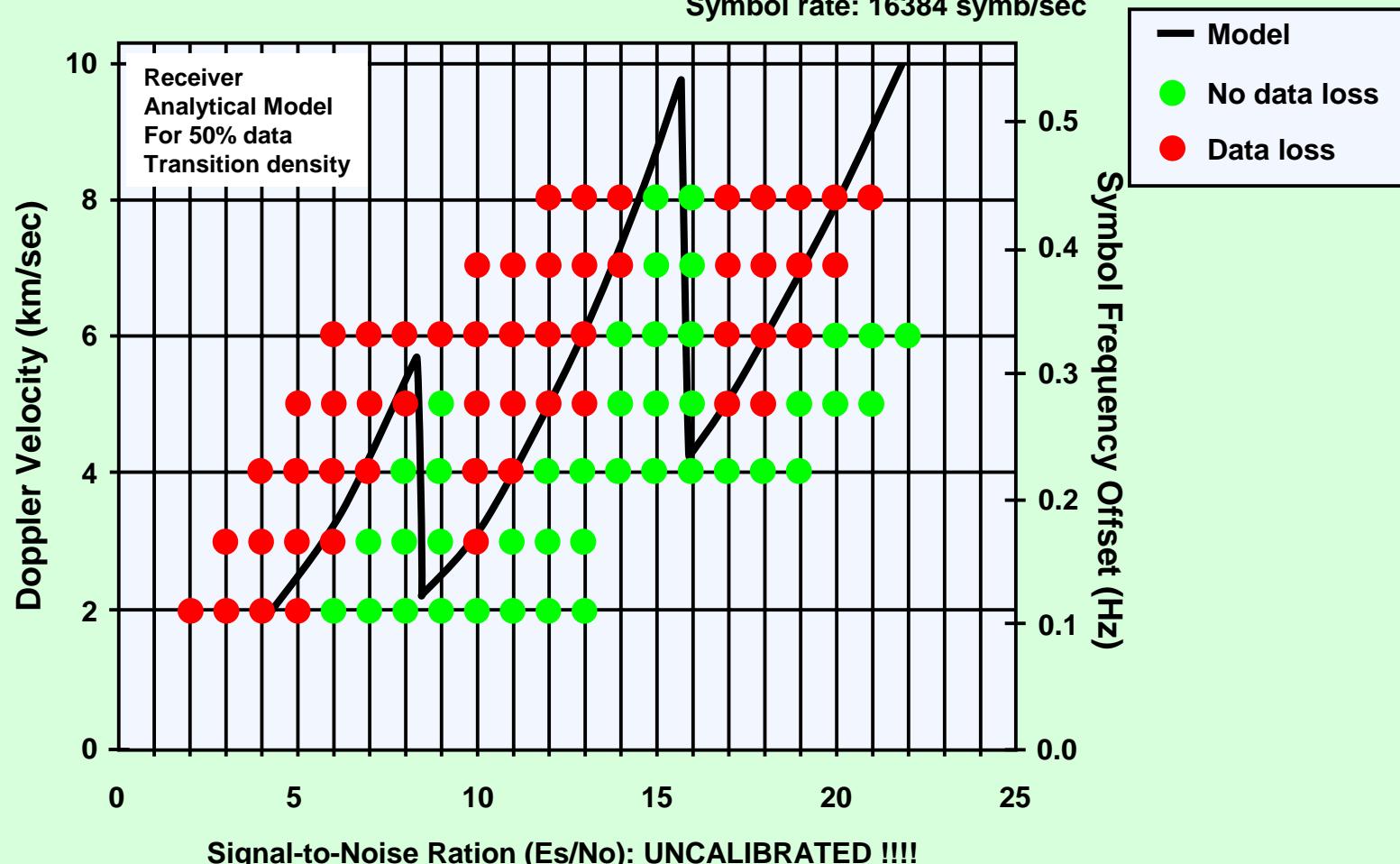
Working to Fix the Huygens Relay Link

PRT 2 Preliminary Results



Channel A; 53% Data Transition Density

Symbol rate: 16384 symb/sec





Working to Fix the Huygens Relay Link

Some Promising Possibilities Being Considered

- Change the Cassini tour so that it passes Titan at a much larger distance to reduce Doppler
- Reduce the relative time of arrival between Huygens and Cassini (ODT) to increase SNR
- Warm up the Huygens oscillator before releasing the probe to reduce frequency offset (equivalent to Doppler)
- Change Huygens entry point to increase SNR
- Gain knowledge of Titan's winds by delaying probe an orbit – allows better Cassini HGA pointing to increase SNR
- Put a CONSCAN algorithm on Cassini to increase SNR
- Insert “zero packets” in data stream to increase bit transitions
- Rewrite ESA’s RS decoder to recover more of the frames returned to Earth
- Use coding to increase bit transitions
- Use coding to absorb hits from anomaly



Working to Fix the Huygens Relay Link

Possibility Possibilities

- The solution may involve combinations of these or other possibilities
- The solution may vary as a function of time during probe descent
- Before we can select solutions, we need to understand
 - The merits of each possibility including science data worth
 - The cost of each possibility (to both ESA and NASA!)
 - The impact of each possibility on the Cassini mission
 - The risk of each possibility
- We must involve the Huygens science team at this point





Working to Fix the Huygens Relay Link Schedule for Decisions



JPL

Probe Relay Recovery Schedule

January 4, 2001

Activity Name	Start Date	2000			2001			2002									
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan
Recovery Team Meeting	10/17/00	▼															
EM Test at ESOC	12/14/00				▼												
EM Test Report	1/16/01				▼												
Test Design for PRT	1/18/01				▼												
DSN Scheduling and Configuration Plan for PRT	1/26/01				▼												
In Flight PRT Complete	2/5/01				▼												
Preliminary Assessment of Recovery Options																	
Changing Orbiter Trajectory	4/1/01									▼							
Modified Use of Flight System	3/15/01								▼								
Rescoped/Descoped Probe Mission (Definition)	4/1/01								▼								
Status Report																	
ESA/JPL/NASA Management	2/1/01				▼			▼	▼								
Pts	1/22/01				▼												
Final Assessment of Recovery Options																	
Report to JPL Management	4/25/01							▼									
Report to JPL/NASA Management	4/27/01							▼									
Report/Recommendations to JPL/NASA/ESA	5/4/01							▼									
Orbiter Trajectory Decision	5/11/01							▼									
Probe Mission Decision	7/27/01									▼							
Tour Redesign and Selection	12/28/01											▼					
Resume SOP Development	1/15/02											▼					
Probe Mission Redesign	12/28/01												▼				
		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan

Working to Fix the Huygens Relay Link

Conclusions (so far!)

- Although the Huygens PSA cannot track data flawlessly, the loss of data will not be nearly as bad as indicated in the initial tests
- There are many possibilities that can improve PSA performance without significant loss of data
- We still need to quantify performance gains, costs, and risks for possible solutions
- We need to pass lessons to future missions:
 - Need better testing before launch
 - Design more flexibility into flight systems
 - Never prohibit information from flowing back to Earth

